The IC CAIG Risk Methodology

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S. S. Gupta (IC CAIG)
31 Jan 2002

- **Primary: To describe the risk methodology used by the IC CAIG**
  - **Full disclosure**
  - **Standardization**

- **Secondary: To provide guidance and offer illumination to IC component cost groups**

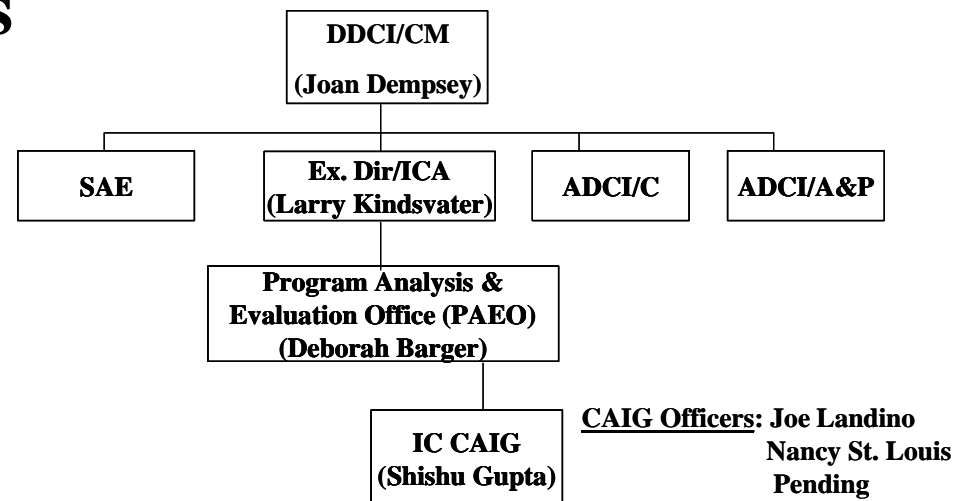- **Tertiary: To advance the state of the art for risk in general**

The IC CAIG

- **DCI-Level Cost Analysis Group established in 1998**
  - Response to recommendations from a DCI Project Review Panel
  - First cost review conducted jointly with OSD CAIG

- **IC CAIG name adopted in 1999 to create rapid familiarity with mission and purpose**

- **Grown to 5 Govt plus Contractor Support**

- **Tasked by**
  - DCI
  - DDCI/CM
  - Congress

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                    │(Joan Dempsey)│
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            │(Shishu Gupta)│
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CAIG Officers: Joe Landino
Nancy St. Louis
Pending
Vacant

Contractor Support: Aerospace
TASC/MCR

- **Perception and reality of cost growth**
  - **Double / triple digit budget growth**
- **Schedule slips on numerous programs**
- **Lack of program baseline data**
- **High Congressional interest (& tasking)**
- **Immature cost analysis infrastructure**
  - **Few cost groups**
  - **Fewer cost databases**
  - **Culture opposed to oversight**
  - **Waiver from DODD 5000**

Evolution of IC CAIG Risk

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- **FIA and USIGS Risk were done in 1999 in the absence of a formalized IC CAIG methodology using separate approaches:**
- **FIA – Historical risk methodology**
  - **Schedule/Technical Risk**
    - Experts assessed CWBS elements using a risk matrix (high-level)
    - Linear, historically derived Risk-Score-to-Risk-Percent Mapping equations were applied – symmetrical risk distributions with rising means
  - **Cost estimating risk:**
    - Standard deviations based on SEE of CERs
    - Symmetrical normals with a small historically derived bias were applied
- **USIGS – Expert-based risk methodology**
  - **Schedule/Technical Risk**
    - Experts assessed on *minimum, most likely and maximum*
    - Some historical risk factors used
  - **Cost estimating risk:**
    - Standard deviations based on SEE of CERs
    - Symmetrical normals with a small historically derived bias were applied
- **Reconciliation conducted with the program office risk teams**

- **Goal: move toward a standardized methodology for risk as briefed here**

- ## Scope of the Estimate
  - Scope limited to the CARD (Contractor/SPO view)
  - Reasonable allowance for scope creep (SPO/PEO view)
  - Basis for future budgets (CAIG/Congressional view)

- ## Self-fulfilling prophecy
  - No evidence either way
  - Will new DoD policy to budget to OSD CAIG estimate shed any light?

- ## Cost Estimating
  (quality of inputs & methods)
  - Error
  - Uncertainty
  - Omission

- ## Schedule/Technical
  (ability to meet the <u>intended</u> design)
  - Technology
    - Tech Readiness
    - Application
  - Performance
  - Management
    - Joint programs
    - Team's experience

- ## Requirements
  (Did design meet intended reqm'ts?)
  - Scope creep
  - Clear Definition

- ## Budget
  (stable funding, proper phasing)
  - Funding profiles
  - Perturbations

- ## Threat
  (Did the <u>problem</u> change?)

Difficult to Budget For; Often Implicit or Omitted

Methodological Issues

- **Linked to historical data (Risk CER)**

- **Schedule Risk**
  - Compression vs Stretch

- **Correlation**
  - Independent elements
  - Functional correlation
  - Among factors
  - Among phases

- **Role/value of expert opinion**
  - Convolution
  - AHP
  - Tech assessments

- **Uncertainty vs Risk**

- **Time phasing of risk**

- **Shape of Risk Distributions**

- **Basic statistics**

The Tenets of IC CAIG Risk

IC CAIG

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- **Cost Primacy: Risk must never be used to correct cost estimation shortcomings or used to bypass or short-circuit cost estimate reconciliation**
  – Errors or shortcomings uncovered in cost estimation are fed back to the cost estimator, not repaired in the risk estimate
  – Exception: the *usual* failure to foresee growth is the province of the risk estimate

- **Cost-Risk Consistency: Risk methods must be in closest possible agreement with cost methods**

- **Risk Consistency: Risk methods must be in closest possible internal agreement**
  – Consistency is not better than being right, but we place great value on internal consistency
  – If inconsistency suggests prior error, we endeavor to correct it

- **Mathematical & Statistical Principles: We strive to follow them**

- **Historical Checks: History is the only sure test of methodologies**
  – This does not mean slavishly repeating history, but rather testing ourselves against history

- **Primacy of Lower Moments: Correct lower order moments more important than higher order**
  – E.g., We want the best possible answer for the mean first, and the highest confidence and lowest CV second, and so on, within reason
  – Extension: We believe that lower order moments are more easily estimated and more stable

- **Improvement: Improvement is the standard, not perfection**
  – Corollary – if a change introduces improvement in any aspect, and no degradation, the change should be accepted

CMS-Risk-Methodology-Manual-v90.ppt

Model Architecture

- **Inputs**

- **Structure**

- **Execution**

General Model Architecture

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Scoring	Inputs	Dollar Basis
• **Interval w/ objective criteria** • **Interval** • **Ordinal** • **None**		• **Historical** • **Domain Experts** • **Conceptual**

Structure

Organization

– **Coverage & Partition**
  - Cost Estimating
  - Schedule / Technical
  - Requirements
  - Threat

– **Assigning Cost to Risk**
  - CERs
  - Direct Assessment of Distribution Parameters
  - Factors
  - Rates

– **Below-the-Line**
  - Yes
  - No

Probability Model

– **Distribution**
  - Normal
  - Log Normal
  - Triangular
  - Beta
  - Other (e.g., Bernoulli)

– **Correlation**
  - Functional
  - Injected historical
  - Relational
  - Injected nominal
  - None

Tip: Higher is generally better

Execution

Compu-tation	Cross Checks
• **Monte Carlo** • **Method of Moments** • **Deterministic**	• **Means** • **CVs** • **Inputs**

Engineers' and Cost Analysts' Views of Risk

Engineers	Cost Analysts

• **Work in physical materials, with**
 	
   – Physics-based causal responses
   – Physical connections
	• **Work in dollars and parameters, with**
	
	   – Statistical relationships
	   – Correlation

• **Typically examine or discuss a specific, discrete outcome**
 	
   – Point Designs
   – Specific System Parameters
	• **Typically examine or discuss a general, continuous outcome set**
	
	   – Probability distributions
	   – Statistical parameters such as mean and standard deviation

• **Typically seek to know:**
 	
   – Given this solution, what will go wrong?
   – Are design margins enough?
	• **Typically seek to know:**
	
	   – Given this relationship, what is the range of possibilities?
	   – Are cost margins enough?

Both views are valid.
Goal is to merge the best qualities of both views.

- # Interval with objective criteria

  - **Set scoring based on objective criteria, and for which the distance (interval) between scores has meaning. (Note: the below example is also Ratio, because it passes through the origin.)**

    - **A schedule slip of 1 week gets a score of 1, a slip of 2 weeks gets a score of 2, a slip of 4 weeks gets a 4, a slip of 5 weeks gets a score of 5, etc.**
    - **The difference between a score of 1 and 2 is as big as a difference between score of 4 and 5**

- # A scale is interval if it <u>behaves</u> as interval under examination*

  - **Superficial appearance is unimportant**

"Nominal, ordinal, interval, and ratio typologies are misleading," P.F. Velleman and L. Wilkinson, *The American Statistician*, 1993, 47(1), 65-72

SCORING	$$ BASIS
ORGANI-ZATION	PROB. MODEL
COMPU-TATION	CROSS CHECKS

Inputs – Scoring

- # Interval
  - ## Set scoring for which the distance (interval) between scores has meaning
    - Low risk is assigned a 1, medium risk is assigned a 5, and a high risk is assigned a 10
    - Note that it is not immediately clear that the above scale is interval, but it is surely not subjected to objective criteria.

- # Ordinal
  - ## Score is relative to the measurement
    - e.g., difficulty in achieving schedule is low, medium, or high

- # None*
  * Note that nominal, while a valid category, is never used in practice

Inputs – Dollar Basis

- ## Historical
  - **Actual costs of similar programs or components of programs are used to predict costs**

- ## Domain Experts
  - **Persons with <u>technical</u> expertise regarding similar programs or program components assess the <u>cost</u> impact based on their experience**

- ## Conceptual[1]
  - **An arbitrary impact is assigned**

[1] **Any scale without a historical basis or expert assessment is "conceptual"**

SCORING	$$ BASIS
ORGANI-ZATION	PROB. MODEL
COMPU-TATION	CROSS CHECKS

- ## How the four types of risk are covered and partitioned

  - ### Cost Estimating

  - ### Schedule/Technical

  - ### Requirements

  - ### Threat

These risk types may be covered implicitly or explicitly in any combination.

SCORING	$$ BASIS
ORGANI-ZATION	PROB. MODEL
COMPU-TATION	CROSS CHECKS

- **Risk CERs: Equations are developed that reflect the relationship between an interval risk score and the cost impact of the risk (this might also be termed a Risk Estimating Relationship (RER))**

  - **These equations are equivalent to CERs in a cost estimate**

  - **Allows <u>technical</u> experts to provide <u>technical</u> risk scores**

  - **e.g., Risk Amount = 0.12 * Risk Score**

- **Direct Assessment of Distribution Parameters: Costs are captured in shifts of parameters of the risk, e.g., shifted end points for triangulars, shifted end points or means for betas, etc.**

  - **Asks <u>technical</u> experts to define <u>cost</u> distributions (e.g., best cost, nominal cost, worst cost)**

SCORING	$$ BASIS
ORGANI-ZATION	PROB. MODEL
COMPU-TATION	CROSS CHECKS

- **Factors: Fractions or percents are used in conjunction with the scores and the cost of the component or program**
  - e.g., a score of 2 increases the cost of the component by 8%
  - Antenna Risk Score = 2
  - Cost of Antenna = $4,090K
  - Risk Amount = 0.08 * 4,090K = $327.2K

- **Rates: Predetermined costs are associated with the scores**
  - e.g., a score of 2 has a cost of $100K
  - Antenna Risk Score = 2
  - Cost of Antenna = $4,090K
  - Risk Amount = $100K

Warning: Rates are independent of the element's cost.

SCORING	$$ BASIS
ORGANI-ZATION	PROB. MODEL
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- # Below-the-Line Elements

  - Elements that are driven by hardware, software, and the like

  - Below-the-Line Elements include:

    - Systems Engineering/Program Management (SE/PM)

    - System Test and Evaluation (ST&E)

  - Not all models account for this cost growth

  - Functional Correlation is an approach to address the risk in these elements

SCORING	$$ BASIS
ORGANI-ZATION	PROB. MODEL
COMPU-TATION	CROSS CHECKS

- **Normal**
  - Best behavior, most iconic
  - Theoretically (although not practically) allows negative costs, which spook some users
  - Symmetric, needs mean shift to reflect propensity for positive growth

- **Lognormal**
  - A natural result in non-linear CERs
  - Indistinguishable from Normal at CVs below 25%
  - Skewed

SCORING	$$ BASIS
ORGANI-ZATION	PROB. MODEL
COMPU-TATION	CROSS CHECKS

Probability Model – Distribution

- ## Triangular
  - **Most common**
  - **Easy to use, easy to understand**
  - **Skewed**

- ## Beta
  - **Solves negative cost and duration issues**
  - **Many parameters – simplifications like PERT Beta are possible**
  - **Skewed**

- ## Bernoulli
  - **Probability is only assigned to two possible outcomes, success and failure (p and q = 1-p)**
  - **Simplest of all discrete distributions**
  - **Mean = p**
  - **Variance = p*(1-p) = p*q**

Probability Model – Correlation

> **Correlation** is a measure of the relation between two or more variables/WBS elements

- **Functional: Arises between source and derivative variables as a result of functional dependency. The lines of the Monte Carlo are cell-referenced wherever relationships are known.**

  – CERs are entered as equations

  – Cell references are left in the spreadsheet

  – When the Monte Carlo runs, input variables fluctuate, and outputs of CERs reflect this

An Overview of Correlation and Functional Dependencies in Cost Risk and Uncertainty Analysis, R. L. Coleman and S. S. Gupta, DoDCAS, 1994

SCORING	INPUTS
ORGANI-ZATION	PROB. MODEL
COMPU-TATION	CROSS CHECKS

Functional Correlation

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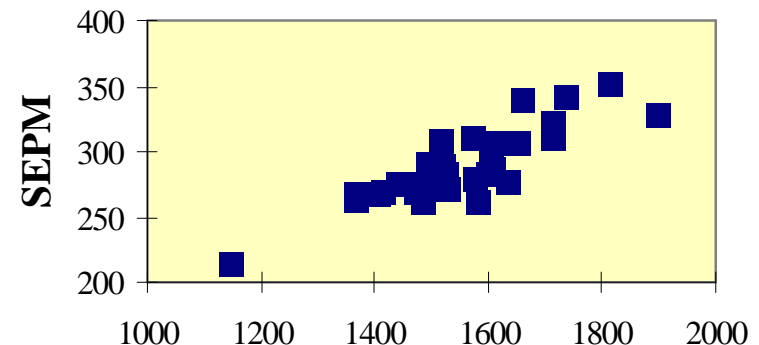
- **Old: No Functional Correlation; Simulation run with WBS items entered as values**
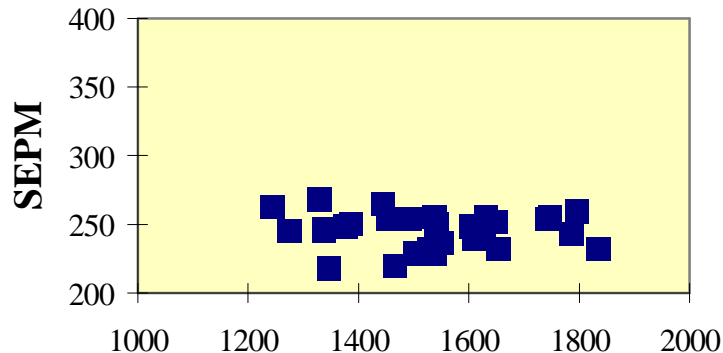
- **New: Simulation run with functional dependencies entered as in the cost model**

Not Correlated

Correlated

Functional correlation "flows risk through" to "Below the Line" CWBS elements, and so increases risk in the cost estimate … as it ought to be increased.
This increase can be a doubling, depending on the CERs and the correlation

Note shift of mean, and increased variability

- **Injected historical: Introduces correlations based on historical data**
  - Usually implemented much like Functional Correlation - but the initial point estimates were derived independently
  - The implicit CER must be checked for reasonableness against the two point estimates
    - Extreme implicit calibration should be avoided.

- **Relational: Introduces the geometry of correlation, provides a substantial improvement over injected nominal correlations, and fills a gap in FC**
  - Relational Correlation provides insight into
    - The tilt of the data, i.e. the regression line,
    - The variance around the regression line

Relational Correlation: What to do when Functional Correlation is Impossible, R. L. Coleman, J. R. Summerville, M. E. Dameron, C. L. Pullen, S. S. Gupta, ISPA/SCEA Joint International Conference, 2001

- **Injected nominal: Imposed by assigning a nominal (e.g., 0.2) correlation directly between variables**

  – Ignores implied regression created by the correlation

  – Arbitrary, but better than nothing

- **None: No relationship exists among the variables. The lines of the Monte Carlo are self-contained.**

- **Monte Carlo: A method, used on a broad range of risk assessments for many years.**
  - Produces cost distributions, giving decision makers insight into the range of possible costs and their associated probabilities

- **Method of Moments: The mean and standard deviation of lower-level WBS lines are known, and are rolled up to provide higher-level distributions.**
  - Easy to calculate
  - Negated by the rapid advances in microcomputer technology
  - Only works for independent elements, unless covariances are allowed for, which is difficult.

- **Deterministic: Only point values are used. No shifts or other probabilistic effects are taken into account.**

SCORING	INPUTS
ORGANI-ZATION	PROB. MODEL
COMPU-TATION	CROSS CHECKS

- **Means**: The mean cost growth factor of the rollup and CWBS elements can be compared to history to cross check results

- **CVs**: The CV of the rollup and CWBS elements can be compared to historical dispersion levels

- **Inputs**: Means and distributions of inputs or other parameters can be compared to history to cross check inputs and assumptions

  – Example: Historical risk scores can be compared to program risk scores to see if risk assessors are being realistic, and whether the underlying database is representative of the program.

SCORING	INPUTS
ORGANI-ZATION	PROB. MODEL
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General Model Architecture

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Inputs

Scoring
- **Interval w/ objective criteria**
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- **Ordinal**
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Dollar Basis
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- **Domain Experts**
- **Conceptual**

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Cross Checks
- **Means**
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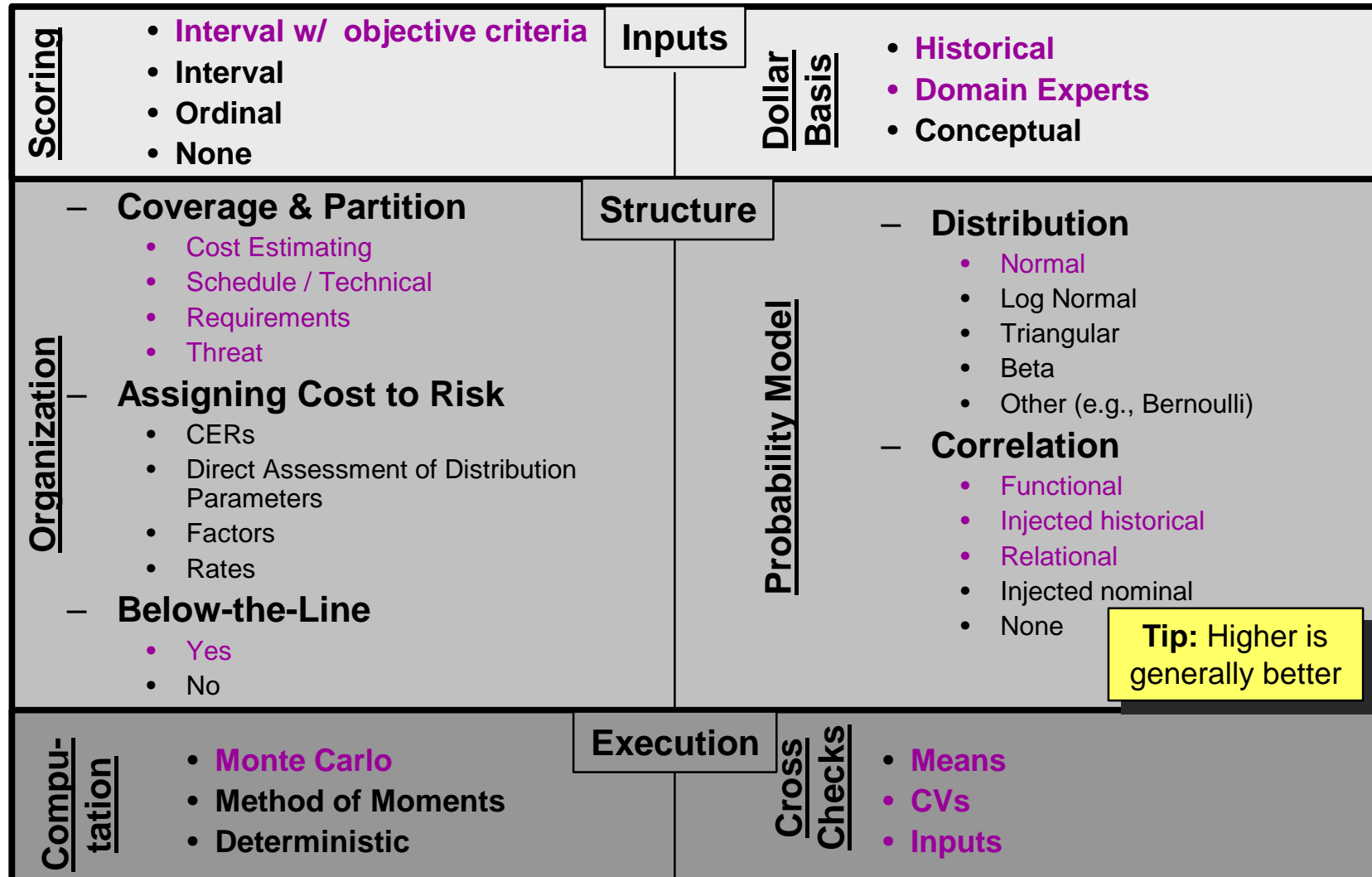
Size Adjustments

Dispersion – Bounds

Note that the Upper and Lower bounds are not symmetric. Also, dispersion is higher for smaller projects … an effect that is captured by the bounds.
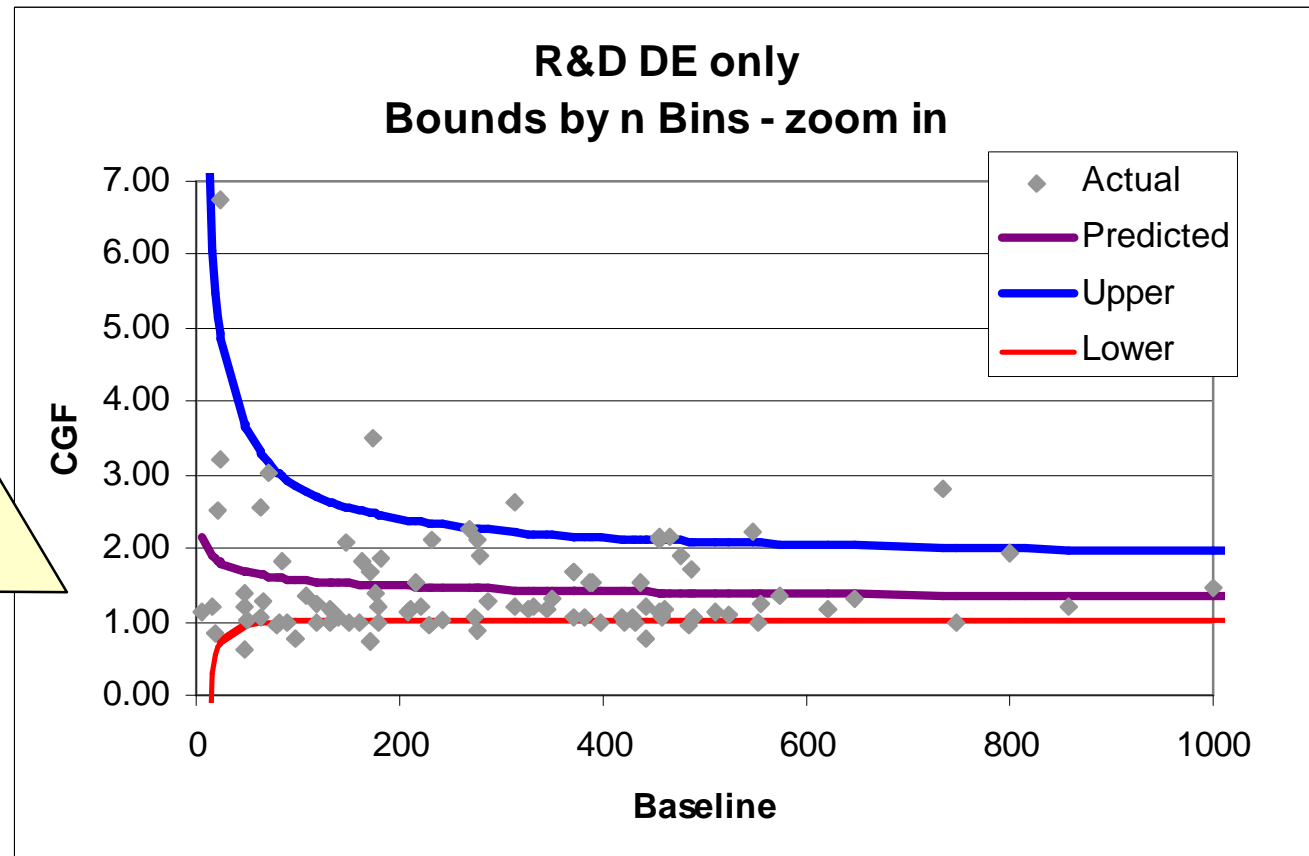
R&D DE only
Bounds by n Bins - zoom in

This converts CGFs

This converts just the risk percent

Size	Predicted CGF	CGF Adj Factor	Risk % Adj Factor
100	1.57	1.25	2.26
250	1.46	1.17	1.83
500	1.39	1.11	1.57
750	1.36	1.09	1.45
1000	1.34	1.07	1.36
1500	1.32	1.05	1.26
2000	1.30	1.04	1.19
3000	1.28	1.02	1.11
4000	1.26	1.01	1.06
5000	1.26	1.00	1.02
5500	1.25	1.00	1.00
6000	1.25	1.00	0.99
7000	1.24	0.99	0.96
8000	1.24	0.99	0.94

Suppose a $1000M program is given a risk of 22% using the risk scores and mapping equations. Then, the 22% risk will be increased by a factor of 1.36 based on the program size, resulting in a total risk of 29.9%.

At $5.5B, risk is not adjusted for size

- **Unknown unknowns (risk) represent a significant source of cost and budget growth**

- **Programs need to begin estimating and budgeting for this "risk"**

- **There are many ways to do risk**
  - Some are better than others
  - Important to strive for improvement
  - Something is better than nothing

- **Challenge: Budgeting for "Risk"**